SOO/DOH IFPS Whitepaper Implementation: Requirements and Approaches

A Report on the 2003 WR SOO/DOH Workshop

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(NOTE: This final version considers comments and reviews received following an earlier distribution to all NWS SOOs/DOHs.)

INTRODUCTION: As the NWS continues toward the Initial Operating Capability (IOC) of the Interactive Forecast Preparation System (IFPS), efforts are underway to collect, identify, and prioritize IFPS science issues and implement agreed upon solutions. One of the earliest efforts was summarized in a NWS Western Region (WR) SOO/DOH IFPS Whitepaper (hereafter in this document referred to as the "Whitepaper") titled *IFPS Implementation, Design, and Impact on NWS Field Forecaster Performance.* This Whitepaper – finalized on 18 November 2002, and subsequently approved by all NWS Regions – identified major scientific issues of the current IFPS design, further outlining eight primary recommendations to address these issues that, if implemented, would better enable the field to produce detailed and accurate digital forecasts and allow for efficient use of human capital. Considered together, these recommendations are intended to better ensure the overall scientific integrity of the digital forecast process.

The May 2003 WR SOO/DOH Workshop held in Salt Lake City, Utah, was designed to define a series of focused requirements and approaches to be considered and directed over the next three months to five years for each of the eight recommendations outlined in the Whitepaper. Workshop participants included WR SOOs and DOHs as well as subject matter experts from academia, NOAA development laboratories, and the NWS Office of Science and Technology. Members of the newly-formed NWS IFPS Science Steering Team (ISST) also attended. Prior to the workshop the eight recommendations were consolidated into five groups by combining common recommendations where possible. These five groups were: Verification, AWIPS and NCEP Data and Model Issues, Graphical Forecast Editor (GFE) Enhancements (including climatology enhancements), Statistical Model Guidance and Downscaling Model Data, and Incorporating Probabilistic Information and Forecasts into the NDFD Grids.

Workshop attendees were each assigned to one of the five groups, with at least one subject matter expert included with each group. Each group was facilitated by a member of the Whitepaper writing team, and was tasked to identify focused requirements and approaches for their respective Whitepaper recommendation(s). Following extended break-out sessions, group summary presentations were then given to all workshop participants for feedback, possible modification, and to achieve broad consensus. This paper documents and summarizes the results of the workshop. Current ISST efforts and our coordination with this team are discussed first, followed by a discussion of several overarching requirements and challenges. Individual presentations addressing requirements and approaches to each of the eight whitepaper recommendations are then given. Brief closing comments end the paper.

IFPS SCIENCE STEERING TEAM (ISST) EFFORTS: One of the first actions taken following the submission of the Whitepaper late last year was the creation of the IFPS Science Steering Team (ISST) by the Science and Technology (S&T) Committee of the National Weather Service Corporate Board. The ISST, which reports directly to the S&T Committee, is composed of field experts (primarily SOOs) representing all Regions within the National Weather Service. Among the first tasks of the ISST is to address the issues raised in the Whitepaper. One intent of this paper is to support this effort. On a longer term, the ISST is designed to take advantage of direct field representation to continue to identify and prioritize ongoing IFPS science issues. Most importantly, it establishes a formal conduit to pass issues identified by those using the new forecast system in the WFOs and operational centers forward to NWS Headquarters management.

In its first efforts, the ISST proceeded with a subset of recommendations that were drawn from the Whitepaper and further distilled at the 2003 WR SOO/DOH Workshop. These were the recommendations that received both broad endorsement at the workshop and were perceived as most likely to benefit from a fast track. Some recommendations – metaphorically referred to as "low-hanging fruit" – are already being implemented. The ISST and the writing team of this paper have been coordinating efforts to ensure they remain complementary. The broad review and field support of this document, which is intended to be the final document from the Whitepaper writing team, provides an important foundation upon which the ISST can base their efforts now and beyond.

OVERARCHING REQUIREMENTS: Very early in our discussions to organize and prioritize the recommendations within each topic, it became clear that there were several that were of such importance, or so integral across several of the breakout topics, that they deserved special recognition and discussion. We have elected to pull these out and identify them as overarching requirements. Not surprisingly, these are also far reaching across many programs and become more difficult to meet without a focused effort and additional resources; thus satisfying these requirements represents a significant challenge to the agency.

Requirement 1: A real-time mesoscale analysis, or an "analysis of record," is critical to the success of IFPS. This gridded analysis must be provided in real time and at a grid spacing that matches the highest-resolution operational forecasts. For this to work effectively there must be standardization of this minimum grid spacing such that efforts in analysis, climatology, verification, and software development are compatible for all offices and programs. The analysis must support all forecast fields, which requires that it be 3-D, include all sensible fields, and include other observations such as "sky cover" and lightning. Realistically, however, this analysis system will need to mature from early prototype 2-D analyses of primary fields. Because this system should be the basis for a gridded verification system, the impact of the model used for the first guess of these gridded analyses needs to be minimized. The analysis is needed for a number of important functions within the new forecast process. Some examples include: long-term verification to provide feedback to the forecaster, performance measures for customers and partners, input into the GFE for short-term forecasts, and to contribute to the development of a forecast grid-matching climate grid. An archive of these analyses must be maintained to meet this latter requirement. This archive should include the real-time analysis and all input data that are needed to perform a re-analysis as the objective analysis package is improved.

It is recognized that producing such an objective analysis is challenging. Yet, its compelling need overrides any motivation to wait for solutions to known deficiencies in current objective surface analysis techniques. For instance, methods to better address data poor areas will need to be investigated, particularly for regions of complex terrain. In the interim, approaches such as masking low-confidence areas for verification purposes could be considered to address these early deficiencies.

As we strive to forecast and deliver information on unprecedented scales, observations will become increasingly important. Not only because there is a fundamental need for such data to generate a realistic analysis of record, but also for inclusion into numerical weather prediction systems. Every effort should be made to ensure the integrity of our existing observing system and any new opportunities to expand this system should be given high priority.

Requirement 2: The difference between point and grid-box average forecasts must be understood by forecasters, customers and partners, and NWS management. Historically, we have provided highly accurate point forecasts for a relatively few select locations served by the NWS. This is possible by combining guidance from powerful statistical tools with skillful and experienced forecasters. In addition to adjusting for model biases, forecasters have been able to devote specific attention to the weather for these precise locations – accounting for site-specific terrain, vegetation, and small-scale climate anomalies. Our partners and customers have grown to expect this accuracy. In contrast, today's forecasts are presented on a uniform grid with a 2.5- or 5-km spacing. The value of this approach is complete coverage of the CWA with reasonably accurate forecasts rather than a few, more-accurate forecasts at specific locations and is the core service enhancement provided by IFPS. There often will be appreciable differences between a well-composed gridded forecast and specific *in situ* point observations. This will be unavoidable and must be recognized and communicated through outreach and education. For partners and customers who require point information, they must be encouraged to develop statistical tools that combine the coarser gridded forecast with local site information. Within the NWS, this dictates that a new baseline for assessing "point" forecast verification in the gridded forecast era be established. A less-desirable alternative would be to continue a true point forecast system for the limited set of CCF points.

Requirement 3: Probabilistic information must be incorporated into the forecast suite to support all NWS operational forecast programs, from WFOs to NCEP forecast centers. The IFPS framework provides a unique opportunity to deliver detailed information to a variety of users. Among these users will be those who want to make cost-benefit decisions and assess risk using probabilistic information. Examples include decisions made with respect to exceeding critical thresholds, such as with winds and snowfall amounts, or in operational applications where a deterministic forecast is not viable, such as in forecasting extended-period winds during tropical cyclone situations. To further support this requirement, there has been growing agreement in the meteorological community over the past decade that forecasts should be presented in probabilistic terms (as expressed by the AMS statement "Enhancing Weather

Information with Probability Forecasts," adopted by the AMS Council on 13 January 2002, http://www.ametsoc.org/AMS/policy/enhancingwxprob_final.html). This was formally recognized in the NWS Vision 2005, which calls for the NWS to provide weather, water, and climate forecasts in probabilistic terms by 2005. While gridded deterministic forecasts will provide value for certain users and applications, it is overdue for us to begin discussions on the best way to transition from a generally deterministic forecast scheme to one that is optimally complemented by probabilistic information. This effort needs to take advantage of current capabilities and be fully sensitive to time and resource limitations.

Requirement 4: Due to the new paradigm introduced by IFPS, the NWS should place renewed emphasis and resources on training for both forecasting staff and NWS customers and partners. The digital forecast process requires training field forecasters on subjects such as better use of numerical model guidance, interpreting the meaning of certain forecast fields (e.g., sky cover), understanding and expressing probabilistic/ensemble information, and incorporating mesoscale theory into practice. Additionally, our customers and partners require training on interpreting forecast fields and the concept of gridded forecasts in general. Since the NWS is a performance-based service organization, improved performance and skill can only be achieved through proper training. It is thus paramount that existing IFPS training efforts be expanded and that sufficient resources allocated for these efforts. Only then can the full potential of IFPS be realized by forecasters, customers and partners.

Requirement 5: A system as complicated and demanding as IFPS requires all groups within the NWS to work together, and in collaboration with external users and subject matter experts. The recent WR SOO/DOH Workshop demonstrated the effectiveness of bringing field experts, developers, and managers together – all those both vested in the system and involved in the decision making process – to solve critical system issues. This model should be followed when groups or teams are needed, and where appropriate, expanded upon to include customers and partners.

Recommended approaches to meet these requirements: The cross-cutting nature of these requirements touches on fundamental research questions and customer and partner requirements. Their importance nonetheless requires that development processes be immediately put in place to explore the most viable paths. To be most efficient, these first steps should leverage off previous experiences and efforts in these areas, working with new resources and focus. It is also likely that these efforts would benefit from early proof-of-concept or rapid-prototyping exercises, particularly since these have already been proven effective within the early development and implementation of IFPS.

1. In order to produce an Analysis of Record as soon as possible, efforts should begin immediately to get this critical part of the digital forecast process into operations. A number of analysis systems and methods have already been designed and implemented by various individuals and research groups; though much more is needed to produce a system compatible with the current IFPS design. To begin this challenging process, a diverse team of experts from both within and outside the NWS should be formed immediately, and chartered to create a roadmap to develop an analysis of record system. The structure of this team should follow that which is outlined in Requirement 5, while going one step further and coordinating with the climatology and verification teams (discussed later in this report). This roadmap should include a thorough evaluation of using existing analysis methods and systems in the current IFPS design, while further focusing system requirements.

2. The current IFPS Professional Development Series (PDS) should be expanded to include a Professional Competency Unit (PCU) entitled "Understanding and Interpreting Digital Forecast Grids and Products." Understanding the difference between point and grid-box average forecasts, and interpreting probabilistic forecast grids, are just two examples of Instructional Components that should be included in this PCU. This training element should be designed for use by field personnel and for customer and partner outreach and education. Outreach and education tools should be made available for field offices whereby they can be tailored for local use. In following the design of a PDS, this PCU can be expanded with time as new forecast fields become available for use and dissemination. In general, the IFPS PDS should become the focus of IFPS training resources and materials – becoming a one-stop digital forecasting training and outreach resource for SOOs/DOHs and WCMs. Furthermore, the design should consider new employees and the Forecaster Development Course.

VERIFICATION: The paradigm shift to digital forecasting requires a significant change in the way NWS forecasts are verified. For example, it is important to know the accuracy of surface-based parameters derived from numerical model guidance used to populate the gridded forecasts. It is equally important to provide verification of the official, forecaster-edited, grids. This feedback is essential to evaluating overall system performance and deficiencies, and further helping to determine future program direction and design.

Requirement 1: The IFPS verification program must be an integral part of the digital forecast system. Its design, implementation, and operation should be directed by a working team fully supported by NWS senior management.

Requirement 2: The verification system should include both gridded and point-based statistics generated from gridded forecasts. Since NWS customers and partners are able to view digital forecasts in both gridded and point form, it's crucial to understand the system's performance in each. The emphasis of this effort should be on the gridded verification element, needed to provide feedback on the overall system integrity and the digital forecast process. In addition, since IFPS produces grid-based point forecasts (PFMs and SFTs), and we give our users point-and-click access to the grids, the system must include a robust point verification element. This must be completed with the routine set of observations, but should also be flexible enough to include as many observations as are available within a CWA. An effective observation quality control system must be used to ensure that the most valid gridded and point verification scores are realized.

Requirement 3: A gridded verification system is critically dependent upon an accurate analysis of record, outlined previously in this paper. The resolution of this analysis must match the minimum agreed upon grid-spacing of the gridded forecast system being verified, be consistent across all offices and between local and national verification efforts, and use all available data sources.

Requirement 4: The verification system should be flexible in its design, allowing forecasters and NWS management to easily interrogate statistics in multiple ways, including in real-time within the GFE. This will enable the forecaster to apply grid bias or correction information to forecast grids when needed. The point verification should also be flexible enough to allow verification of point observations by user-defined zones or areas to determine any local biases.

Recommended approaches to meet these requirements:

1. We recommend that the NWS form a permanent team with broad representation to direct the IFPS verification system. This team should be specifically tasked to: define verification needs for the agency, ensure adequate funding and support for all verification efforts, establish consistency across all verification programs, and make certain that other ongoing and future development efforts that contribute to meeting these requirements are identified and accelerated through adequate support. As opposed to the current National Verification Integrated Work Team, this new team's charter should be ongoing and should establish a broader base by tapping expertise external to the agency as peer group reviewers (e.g., universities and research laboratories). Members should include field experts and represent all NWS Regions, NCEP and NWSHQ (OS/OST/OH).

2. We recommend immediate efforts be made to enhance the Daily Forecast Critique (DFC) to provide basic gridded and point statistics of model and forecast elements. The DFC should be directly integrated within the GFE framework, allowing forecasters to apply verification information (e.g., bias corrections) to gridded forecasts. As a first step, DFC development and refinement should proceed in a Rapid Prototype Project-like effort designed to establish requirements and test software in a responsive fashion through collaboration between the NOAA/Forecast System Laboratory (FSL) and a selected set of NWS field offices that have already gained experience in IFPS verification.

3. NWS/MDL should continue with prototype efforts to create a national gridded verification system using available high-resolution analyses (e.g., 20-km RUC, 2.5-km Western Region ADAS) and with the latest methodologies.

AWIPS AND NCEP DATA AND MODEL ISSUES: The most fundamental data used by forecasters in IFPS are gridded model data. While the NCEP models continue to increase in temporal and spatial resolution, and are integrated progressively farther out in time, field forecasters have been and continue to be forced to work with degraded data sets. This was acceptable practice in the past since forecasters had little or no way of communicating native model resolution and detail to customers and partners. The introduction of IFPS presents a new data requirement.

In the current IFPS design, forecasters are forced to manually adjust for detail resolved by the models, yet removed by the transfer of degraded resolution data. To help resolve this system deficiency, NCEP model data must be delivered at native horizontal resolution to better match the operational IFPS grid spacing. Detailed vertical model output – in particular at lower levels – is also needed to improve upon current "SmartInit" procedures, which take model data and produce sensible surface weather data not explicitly forecast by numerical models, and downscale to forecast grid spacing. Forecasters must correct for SmartInit limitations through tools created locally or obtained through the Smart Tool Repository. By delivering the best possible first-guess grids, forecaster resources are freed to make local adjustments to the gridded forecasts, maintain better situational awareness, and devote critical time to serve the watch, warning and advisory program.

Requirement: NWS field offices and NCEP forecast centers require the latest high resolution numerical model data and derived products from NCEP's Environmental Modeling Center (EMC). There currently is little relationship between the resolution and forecast (integration) length of the EMC models and what is actually delivered to the field. New EMC model output typically takes months and often years before it is available to field forecasters, and sometimes never at all. The number of experimental products from EMC is also increasing and should be considered for dissemination to field offices for use in AWIPS and IFPS. Examples include medium-range ensemble forecast products, and EMC's short-range (0-3 days) ensemble forecast system (SREF), which produces guidance on the probability distribution of weather elements or events, such as quantitative precipitation forecasts (QPFs).

A new methodology is needed to determine NWS field office data requirements, and how to efficiently implement the delivery of these required data sets. This system needs to be flexible so that as NCEP grid resolutions and model suites change, or as new data sets become available, required changes or additions can easily and quickly propagate to the SBN as well as to AWIPS and IFPS software applications.

Recommended approaches to meet this requirement:

1. A permanent AWIPS/IFPS data requirements team should be assembled. This team should ensure a complete, end-to-end data delivery process is in place, and remain vigilant in determining what datasets (grids, satellite, radar, etc) are needed in the field. The team should comprise at least the following:

- NWS WFO personnel from each region and NCEP field offices – to determine field requirements.
- NCEP EMC – to coordinate model changes and post-processing.
- OST – to determine data set availability, SBN constraints, and NOAAport issues.
- FSL and MDL – determine impacts to D2D and IFPS software.

2. The SBN should be utilized to its full capacity. The SBN is currently under-utilized at certain times of the day, typically after the GFS model has been disseminated. To take advantage of these data transmission lulls, additional products should be added to the SBN in the next few months, ideally before IOC (30 September 2003). These data sets should include additional vertical levels of the GFS model as well as more Eta 12-km output. It is recognized that some of these data sets will be delivered after the initial suite of Eta and GFS data (i.e., a latency of 30-90 minutes). The appendix to this report includes a prioritized list of these required data sets as agreed upon at the WR SOO/DOH Workshop.

3. New techniques to increase data flow to the field should be developed. We endorse the planned implementation of compression techniques and NOAAPort upgrade to the Digital Video Broadcast-Satellite (DVB-S) during the upcoming 12-18 months. These will significantly increase capacity for delivery of high resolution model grids needed for IFPS. However, we are concerned that the current AWIPS hardware (including the new Linux PX) may not be able to adequately meet the processing and storage needs of these high resolution data sets. As such, a complete end-to-end evaluation of data delivery should be performed to ensure broadcast data are viewable and useable in forecast operations. Any system deficiencies should be addressed in a timely manner. The appendix includes a list of additional data set requirements agreed upon at the WR SOO/DOH workshop that can utilize the DVB-S technology.

4. Surface analyses of complementary data, such as sea surface temperatures (SST), ice, and snow cover, are needed by field forecasters for use in IFPS. These analyses currently exist in gridded form at various centers and agencies, and should be made available on the SBN, preferably before the start of the IOC.

CLIMATOLOGY: Climatology has always played an important role in the forecast process, both in verification and calibration. Accurate high-resolution climate grids of all forecast variables are essential to serve as background fields for analysis and verification in IFPS, and to generate useful probabilistic forecasts, a stated goal within the NWS Vision 2005. Climate grids are vital to forecasters as another guidance tool for populating grids during situations considered to be climatologically normal. Additionally, forecasters should have tools to create phenomena-specific grids (composites) to be used in situations that operational numerical models cannot yet represent, such as mountain windstorm events. Based on these needs, two different climate databases were deemed necessary by the workshop participants in order to realize the full potential of climate grids within IFPS. These two types are (1) a long-term climate average, and (2) a user-selectable dynamic database that allows regime or conditional sampling.

Requirement 1: Field offices and NCEP forecast centers need national seamless climate grids of all IFPS forecast variables at full IFPS grid resolution, which as stated earlier, should match the analysis and verification grids. This is of paramount importance so that these grids can be easily integrated not only into the GFE, but also be used as potential background fields for analysis or verification grids, or in the future, probabilistic grids. The climate grids should be developed using the same techniques as the analysis and verification grids, so that all three are comparable. There's also a need for sub-daily, in some cases up to hourly, climate grids to match the temporal resolution of the operational forecast. These grids should be derived from all available reliable data points and any mesoscale data sources (satellite, radar, and lightning) that could help augment more widely scattered surface data. For example, satellite-derived temperatures, using surface observations to anchor values, could be applied in data sparse regions to generate a more robust gridded temperature field. Finally, these climate grids should be maintained nationally and updated routinely in order to incorporate new observations and better account for climate change. This is also necessary to utilize any improved methods of data analysis that are developed in the future.

Requirement 2: To be useful in future probabilistic forecasting methodologies, climate distributions around the mean will need to be determined for each forecast variable. These should be developed in the form of mean and spread distributions. Model climate grids will also be needed for post-processing of numerical model output and probabilistic forecasting.

Requirement 3: Field offices need a user-selectable, dynamic climate database system. This system should be nationally supported and well-documented, and include tools and applications to determine critical local regime-based, conditional climate grids. This dynamic climate database system can be used to generate better first-guess fields for some local phenomena than those taken directly from our current numerical modeling system. Such applications include creating and subsequently applying a wind grid representing a typical down slope windstorm, or a diurnal mountain drainage flow.

Recommended approaches to meet these requirements:

1. A diverse team of NWS and non-NWS climate and analysis experts should be assembled to design and oversee a national gridded climate database program. This effort should parallel work on the development of analysis and verification grids, so that the climate database can be cross-utilized in these as well as the operational forecast. Given the urgent need for climate grids, this team should explore the possibility of retroactively creating such grids using similar analysis techniques on currently archived observations. EMC is currently completing a 25-year regional reanalysis on a 32-km grid, and at a 3-h resolution. This should provide strong foundation for these new efforts.

2. Preparatory work should begin now, likely involving NCDC, to ensure the infrastructure to create a national archive of analysis and verification grids is ready as soon these grids become available. This archive should include the real-time analysis and all input data that are needed to perform a re-analysis as the objective analysis package is improved.

3. A user-selectable, dynamic climate database system should be developed. This system should contain a flexible set of tools and applications that access the national climate archive to create regime or conditional-based climate grids.

4. The NWS should investigate the benefits of using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) datasets as a first step toward incorporating gridded climate fields into IFPS. Some field offices have already begun to use these data, and these local efforts should be encouraged and nationally supported. We realize that PRISM has inherent deficiencies (e.g., an outdated database, and available for only a small set of IFPS forecast fields), but its early use would give forecasters early experience in using climate data in the digital forecast process. In addition, its use would allow these deficiencies to be documented, and help in the development of an official gridded climate database.

ENHANCEMENTS TO THE GFE: The Graphical Forecast Editor (GFE) is a key tool used to produce the digital forecast grids within IFPS. This software contains both simple and complex grid editing tools, procedures that can account for simple physical relationships, and formatters to produce text products from the grids. Field forecasters have, mainly out of necessity, been highly innovative in creating GFE tools that are shared through the Smart Tool Repository. However, it's been determined over time and through experience in working with forecast grids that further GFE enhancements are needed. The sophistication of these additional enhancements requires that their development be tasked to GFE developers, not users in the field.

Requirement 1: Real-time satellite, radar, and best-available surface analyses should be displayable in the GFE and in a form that can be directly integrated into the forecast grids. From the onset of the NWS Modernization, many assets have gone into addressing short-term (0-12 hr) mesoscale forecasting, which is considered a core mission of the agency. Yet the current IFPS configuration lacks the capability to efficiently and accurately prepare digital forecasts on this time- and space-scale. For example, there is currently no way to ingest and display many real time data in the GFE. Most notably absent are satellite and radar data. Incorporating these data, and developing the tools to manipulate them, will better ensure credibility of this information considered vital to NWS customers and partners. Their availability would immediately improve the forecaster's situational awareness as they continually need to balance attention between forecast grid preparation and the ongoing weather watch.

Requirement 2: The GFE software must include real-time feature identification and extrapolation tools. This is required to more accurately portray the current weather situation and to aid in the preparation of skillful short-term forecast grids. Further, since the time increment of many fields is shorter than those available from the operational suite of models, forecasters are routinely interpolating between coarser temporal grids to fill in, for example, 1 or 3-h grids. Unfortunately, the current temporal interpolation tool is a pixel by pixel linear interpolation. This simply does not work for propagating weather systems. For example, a frontal band in the western part of a domain at one time, and then 12 hours later it is in the eastern part of the domain, it would be very helpful if the forecaster were able to fill in hourly positions by using the temporal interpolation tool. The current scheme would only show the western front fade with time and the eastern front show up and brighten. The front would never move from west to east.

Requirement 3: New and potentially useful gridded fields and data sets need to be incorporated in the GFE as soon as they become available. A process to quickly develop or modify existing

SmartInit procedures to use these new data sets is also needed.

Recommended approaches to meet these requirements:

1. Development work on GFE enhancements to ingest, display, and manipulate real-time data, specifically satellite and radar, should begin immediately. Efforts should build from existing techniques to display these digital data, such as those for radar developed at the NEXRAD Operational Support Facility, or by enhancing the use of the NOAA/FSL Local Analysis and Prediction System (LAPS) in GFE. Since the temporal resolution of these data sets is sub-hourly, techniques to display them in hourly time-steps – the minimum temporal resolution displayable by the GFE – will need to be developed.

2. Efforts that tap into existing expertise, such as at NESDIS, are needed to create a true multi-sensor-based analysis of "sky cover," which is one of the most challenging real-time forecast grids currently being produced. These efforts should build upon existing, multi-sensor, analysis system designs (e.g., LAPS and ADAS), and should be initiated now in order to support the field as quickly as possible.

3. Tools should be developed that easily update and blend real-time data sets with the short-term gridded forecasts. Existing and possibly new interpolation and tracking methods should be incorporated into the design of these tools. A temporal interpolation tool that accounts for system propagation is of very high priority; for example, such a tool is essential for forecasters to correctly and efficiently adjust forecasts for tropical cyclones since TPC's TCM grids do not provide the required temporal resolution.

4. The GFE should be modified to display model short- and long-term ensemble information, such as mean and spread, as a first step toward operational probabilistic forecasting. Tools and utilities will need to be developed to manipulate and use these new data sets in the GFE, including possibly a point-and-click window display of information contained in derived probability density functions (PDF; discussed in greater detail in a later section of this paper).

5. A documented and ongoing process should be developed to quickly move any applicable gridded data set into the GFE. The work recommended in Approach (4) above represents one such example. This process must be designed for universal application to new data sets. In order to optimally use and display these additional gridded data sets as they become available, improved and robust SmartInit capabilities need to be developed.

6. Efforts should begin immediately to evaluate both baseline and field-modified SmartInit procedures through a proposed SmartInit Focus Group. This group must include NWS field experts who, through their considerable contribution to SmartInit development thus far, represent a valuable source of relevant knowledge and user experience. EMC should also evaluate using SmartInit procedures in-house on native resolution NCEP model data – which are immediately accessible given their proximity to the supercomputer – prior to delivery of model output to the field.

STATISTICAL POST-PROCESSING TECHNIQUES AND DOWNSCALING: As was noted in the Whitepaper, and as already stated in this paper, it is of paramount importance that forecasters be given the highest quality model grids used to populate the official forecast grids. Untested SmartInit procedures, uncorrected model biases, and degraded numerical model data delivered to the field require forecasters to spend far too much time on manual editing. This unnecessarily detracts from the forecast and warning process, and short-term situational awareness. To help resolve this issue, forecasters must not only be provided with model output at full spatial (native-grid) resolution, but, in addition, statistically post-processed guidance. This guidance has been shown to provide improvement over raw model output and must be incorporated in to the digital forecast process.

Requirement 1: Since the highest-resolution operational models are, and will likely continue to be, coarser than the grid resolution used in IFPS, efficient and skillful ways to downscale from the resolution of the model grid to the higher-resolution GFE grid are needed. This downscaling most likely would be done from the full-model-resolution forecast fields and not the already-degraded resolutions presently being sent to the forecast offices.

Requirement 2: The oftentimes substantial biases inherent in all operational model output must be removed before this output can be optimally used in the GFE. There is currently no objective means of performing such a bias removal in the IFPS design. Though some of this operation may always be performed manually through forecaster edits, the degree of bias removal subjectively applied in the current system is an unnecessary drain on vital human resources, and likely not optimally skillful. Most of this operation is more effectively and efficiently performed through objective post-processing of model data prior to populating forecast grids.

Requirement 3: Techniques must be developed to incorporate within IFPS statistical relationships between the forecast quantity of interest and various other model output parameters, observations, and climate data. It is well-recognized that statistical post-processing provides significant improvement in forecast quality over simpler direct use of raw model output. Even simple and rather primitive techniques like MOS already provide forecasts quite competitive with those produced by skilled and locally experienced human forecasters; much more sophisticated, state-of-the-art, nonlinear (e.g., "neural net") approaches should do even better. As in requirement (1) above, however, it is critical that these statistical techniques be applied on the actual scale of the operational high-resolution IFPS grids (i.e., MOS directly derived on a discrete grid). Spreading out relatively sparse station-derived statistical guidance will be much less effective, especially in areas of complex terrain.

Recommended approaches to meet these requirements:

1. The task of downscaling to the resolution of IFPS operational grids may, for some forecast parameters, be accomplished through the application of very-high resolution (i.e., approximate match to IFPS grid) dynamical forecast models, run either centrally or locally. These models could potentially be either full-physics mesoscale prognostic models (e.g., the Eta or PSU-NCAR MM5) or high-resolution parameter-specific diagnostic models, such as the Winds on a Critical Streamline Surface (WOCSS) model. At present, it is not fully known what potential options exist; therefore, we also recommend that a scoping study be conducted to investigate all potentially-applicable models.

Any downscaling models that are ultimately distributed for use at local forecast offices must be configured in a standardized “turn-key” format. In the alternative, a significant degradation in the quality and consistency of the NDFD would be expected, as each office uses its own unique downscaling technique. Those offices with more limited local computing expertise may also simply lack the resources to implement any such post-processing model.

2. Current research efforts to objectively remove model biases should be supported and expanded upon for implementation into the IFPS framework. This includes work taking place within universities, which should be supported through appropriate collaborative and cooperative funding sources.

3. Research on the development and implementation of various requisite statistical guidance tools should be conducted both by MDL and NCEP (EMC) and through funding provided to appropriate extramural (i.e., non-NWS) institutions. Particular emphasis should be placed on finding the optimal means for producing gridded MOS-like guidance. MDL is already working on significantly expanding the number of GFS MOS points, which, by fall 2003, is expected to include T_{max} and T_{min} out 10 days for METAR, Co-op, buoy, and CMAN sites. Although we strongly support these efforts, further attention will need to be given to determine the optimal means for producing the statistically-based forecasts *in gridded form.* Once a national verification and analysis system is developed and a sufficient amount of data are archived, statistical guidance for each grid box becomes a viable alternative; particularly if re-analysis grids are used. In the interim, collaborative efforts are needed to determine whether to first develop the guidance for a discrete set of specific points, then use these to derive the corresponding value for each grid cell using existing Smart Tools (e.g., a serpentine fit tool), or to directly develop the guidance for the individual grid cells.

INCORPORATING PROBABILISTIC INFORMATION/FORECASTS INTO THE NDFD GRIDS: Scientists have made significant advances over the last few decades in understanding the role of chaos in weather forecasting. In light of these advances, it has become clear that probabilistic information is needed to make optimal decisions about the future state of the atmosphere. This need has been formally communicated in the NWS Vision 2005, which calls for the NWS to provide weather, water and climate forecasts in probabilistic terms by that time. The NWS has made steady progress in a few areas, including the research and development of short- and medium-range ensembles, probabilistic hurricane track forecasts, probabilistic forecasts of severe weather, and ensemble-based model output statistics (MOS). Yet, very little progress has been made in incorporating probabilistic information into the general product suite of the WFOs. More critical is the fact there are no design features or capabilities within IFPS targeting such a transition.

Requirement 1: Probabilistic information must be delivered to forecasters, customers and partners. The delivery process, which must encapsulate a complete end-to-end design from delivery to display and usability, must provide useful probabilistic information without overloading NWS data transmission, storage infrastructures, and human resources.

Requirement 2: Software utilities and tools are needed that allow forecasters, customers and partners to view and manipulate probabilistic data. Forecasters will need tools to interrogate and possibly edit probabilistic information prior to publishing their forecasts, while external users will need software applications to query the gridded database and extract probabilistic information tailored to their needs.

Requirement 3: Training on the interpretation and use of this new probabilistic information is needed for both internal and external users. Forecasters will need to further their knowledge of the science underlying probabilistic weather forecasting, learn new skills for interrogating and editing probabilistic data, and helping customers and partners interpret these data. To meet this latter requirement, an aggressive outreach program will be required to educate customers and partners on its proper interpretation and use.

Requirement 4: Convincing feedback on issues regarding tropical cyclone winds in IFPS was received following distribution of the first draft of this paper. We recognize this as a critical issue and support the ongoing efforts of the Tropical Cyclone Working Group, which has already begun to examine this concern in depth. This issue dramatically illustrates the difficulty of using deterministic forecasts for extreme events, as well as the need to coordinate forecasts between national centers and WFOs during such events. Highest priority should be placed on system designs that ensure consistent and valuable service to the public and emergency managers, who are faced with making critical preparedness decisions during tropical storms, hurricanes, and other extreme events.

Recommended approaches to meet these requirements:

1. NCEP short- and medium-range, bias-corrected, ensemble forecasts must be delivered to forecast offices and National Centers, and in a form whereby it can be used directly in the digital forecast process. Currently forecast offices receive limited ensemble output in AWIPS out to 84 hours, but this dataset should be expanded as defined in the appendix.

2. A Probabilistic Working Group – consisting of subject matter experts and representatives from NWS field offices and headquarters – should be formed to coordinate with the ISST and advise the Science and Technology Committee of the Corporate Board on issues regarding the research and development of probabilistic forecasts and services. Research efforts the working group should help organize include:

- The development of objective, automated methods to approximate PDFs within a gridded database. The methods must provide reliable and skillful estimates of the PDF. Bimodal distributions should be considered, for example, when light rain and heavy rain are almost equally likely. It may be that different methods will work better for different weather elements.

- Identifying methods for blending automated approximations of the PDF with human created forecast grids. These methods will have to reconcile the mode of the automated PDF, which is by definition the most likely outcome, with the human created forecast grids which the forecaster has determined to be most likely. Further, a forecaster's subjective confidence may be different from the uncertainty (spread) indicated by an objective approximation to the PDF. Therefore, a method will be needed to blend the automated and human derived information (if shown to be advantageous) so that a consistent message is provided to NWS customers and partners.

- Investigating how users make decisions and how probabilistic information impacts these decisions. Customer feedback must play a role in determining how probabilistic information can be tailored to meet their requirements.

- Determining how ensemble and PDF data should be summarized and displayed in AWIPS. Ensemble output from various operational centers and quasi-operational products such as the MDL ensemble MOS box-and-whisker plots at The Pennsylvania State University web site (http://eyewall.met.psu.edu/mos), and EMC short range ensemble precipitation probability of exceedance products, are available now via the Internet. It is critical to not only continue the development of such innovative products, but also make these types of data and displays available in AWIPS, and ultimately in gridded form in the GFE where they can be used efficiently in the forecast process.

- A comprehensive and adequately supported training plan designed to focus IFPS-specific training for forecasters, including use and interpretation of gridded probabilistic information. The program should also include an aggressive outreach plan intended to educate customers and partners on the interpretation of gridded forecast and probabilistic information.

SUMMARY: IFPS represents an extreme but necessary shift in the way official NWS forecasts are produced and interrogated by NWS customers and partners. The Whitepaper put forth eight major recommendations that are strongly believed will help ensure the scientific integrity of the digital forecast process, and ultimately help direct the success of the agency's service to customers and partners. In nearly unprecedented form, whereby field experts were brought together with subject matter experts and NWS managers, the 2003 WR SOO/DOH workshop set out to establish specific requirements and approaches to satisfy these eight recommendations. The results of the workshop that are summarized in this paper, and of which considers reviews and the support of all NWS SOOs and DOHS through an earlier draft, are intended to provide a first step for possible courses of action. The formation of the ISST established a formal conduit to relay these actions to empowered decision makers. A system is now in place that allows future IFPS science issues raised by the field to be efficiently sent forward for quick and proper resolve.

Appendix

Requested New Data for GFE Ingest

Delivered by IOC 30 September 2003, and using under-utilized SBN time. Data sets are listed in order of priority. This list has already been forwarded to NWS Senior Management by the ISST.

- GFS additional levels at 80 km with:
    - Sfc, BL (0-30, 30-60, 60-90, 90-120, 120-150, 150-180) 1000-500 mb x 25 mb, 500-100 mb x 50 mb
    - 0-168 hrs in 6-hr increments, 4 times/day
- Eta 12-km surface and BL (0-30, 30-60, 60-90, 90-120, 120-150, 150-180) through 84 hrs
- Eta 40-km data 60-84 hrs in 3-hr increments, 4 times/day
- Eta 12-km pressure level data 0-84 hrs, 3 hourly increments, 4 times/day. 1000-500mb x 25 mb, 500-100 x 50 mb. (z, t, u, v, rh, not omega) (more useful for complex terrain areas, but also needed for Mixing height, freezing/snow level)
- MREF 84-240 hrs (same fields as currently available 0-84)
- GFS BUFR sounding data

Delivered with implementation of DVB-S. Data sets are listed in order of priority.

- Change GFS from 80 km to current native resolution – all parameters and levels
- Ensemble (MREF and SREF) mean/spread/probability/member grids
- Change RUC from 80/40 km to current native resolution – all parameters and levels
- ECMWF fields similar to GFS out to 168 hrs
- Canadian model fields similar to GFS out to 168 hrs
- UKMET fields similar to GFS out to 168 hrs

- Additional GFS vertical level data 168-240 hrs
- High resolution Eta 12-m omega, all levels, all hours
- WW3 out to 168 hours
- GFDL hurricane grids
- NMM 8-km regional runs